A CRITICAL ANALYSIS OF SOME "FACTORS" IN ELECTRIC UTILITY PRACTICE

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SUMMARY

Numerous "factors" are used in power economy analysis, system planning, rates, etc. A review of many papers and numerous discussions reveals the fact that considerable confusion prevails not only in regard to the significance of various factors, but also in regard to their meaning. The following discussion is presented as an attempt to clarify the meaning and significance of the factors more commonly used. Before proceeding with an individual discussion of each factor, it is important to be reminded that a factor is always a ratio between two values and is more mathematical than physical by nature.

A CRITICAL ANALYSIS OF SOME "FACTORS" IN ELECTRIC UTILITY PRACTICE

I. THE POWER FACTOR. The power factor, particularly the multi-phase factor, is one of the most complex concepts in electrical engineering.

From a business viewpoint, it may be said that the power factor is important because with a low power factor more investment in facilities is required for the same energy or power than with a higher power factor. Hence, the power factor may be said to be principally a fixed charge feature, and may become of considerable importance in the computation and allocation of the cost of power. But it is also an important operating and design feature because it affects voltage regulation as well as the balance and stability of the power system. Power factor penalty clauses in power contracts, therefore, are not only for the purpose of burdening a consumer with his equitable share of the cost, but also to induce the consumer to operate at as good a power factor as he can and thus to contribute his share to the operating advantages derived from a good over-all system power factor.

Even though many power contracts and rate schedules contain clauses which provide for an adjustment in the bill when the power factor differs from a given value, only very few establish a definition for the power factor or a method of determining the power factor for billing purposes. The power factor may be different in each phase of a circuit, the multi-phase power factor may be different from the power factor of any phase, and even the power factor of one phase may vary from instant to instant. Some averaging method must therefore be provided for billing purposes, but very few power contracts provide such a method. The definition in the Glossary of Terms of the Federal Power Commission which is one of several existing practical definitions is: The ratio of power to apparent power. Averaged over a period, it can be expressed mathematically as:

$$\frac{\sum_{t_1}^{t_2} KW}{\sum_{t_1}^{t_2} KVA} \times 100$$

in which t_1 is the beginning and t_2 the end of the period over which the power factor is averaged, say the billing period, or the hour of highest power factor.

$\sum_{t_1}^{t_2}$ KW represents merely the kwh reported by a meter for the period and $\sum_{t_1}^{t_2}$ KVA the kvah reported by a kva hour meter for the same period. This method takes care of all the above variations. But both a kilowatt-hour meter and a kilovolt-ampere-hour meter are required for the purpose.

A CRITICAL ANALYSIS OF POWER FACTORS
IN ELECTRIC UTILITY SERVICE.

I. THE POWER FACTOR. The power factor, particularly the multi-phase factor, is one of the most complex concepts in electrical engineering.

From a business viewpoint, it can be said that the power factor is important because when a low power factor load is connected, facilities are required for the same supply of power than with a higher power factor. Hence, the power factor may be said to be principally a fixed charge problem, and has become of considerable importance in the computation and allocation of the cost of power. But it is also an important operating and design problem because it affects voltage regulation as well as the capacity and stability of the power system. Power factor penalty clauses in power contracts, therefore, are not only for the purpose of recovering a customer share the equitable share of the cost, but also to induce the customer to operate at as good a power factor as he can and thus to contribute his share to the operating advantages resulting from a good over-all system power factor.

Even though many power contracts and rate schedules contain clauses which provide for an adjustment in the bill when the power factor departs from a given value, only very few contain a definition for the power factor or a method of determining the power factor for billing purposes. The power factor may be different in each phase of a circuit, the multi-phase power factor may be different from the power factor of any phase, and the power factor of any phase may vary from instant to instant. Some contracts assume that this is no problem for billing purposes, but only few power contracts contain such a method. One definition is the Glossary of Terms of the Federal Power Commission which is one of several uniform electrical definitions for the ratio of power to apparent power. Averaged over a period, it

can be expressed mathematically as: $\dfrac{\int_{t_1}^{t_2} KW}{\int_{t_1}^{t_2} KVA} \times 100$ in which t_1

is the beginning and t_2 the end of the period over which the power factor is computed, say the billing period, or the time of highest power factor.

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This method takes care of all the above variations. But both a watthour and a kilovoltampere-hour meter are required for the purpose.

2. THE LOAD FACTOR. The load factor is probably the most used and most abused of all factors. It is the ratio of the average load over a designated period to the peak load occurring in that period and relates either to a consumer's load, the load on a power house or the load on a power system. It may be averaged over a month or over a year. It may be based on instantaneous peak, 15-minute peak or hourly peak. It is generally based on kw but sometimes on kva. Thus when the term load factor is used a number of qualifying statements are necessary. Furthermore, the load factor has no relationship to capacity and consequently no relationship to cost. A power house of 100,000 kw capacity may have a peak load of 80,000 kw and a load factor of 95 percent or it may have a peak of 5 kw and also a load factor of 95 percent. The load factor can be determined from a load curve without even knowing the scale to which the curve is plotted. Thus the frequently made statement that when a power house operates at a certain load factor the energy costs so much per kwh, is meaningless. As far as cost analysis of a power house or a power system is concerned, the load factor only assumes a practical meaning when either the energy or the peak with its qualifications as well as the capacity are also known. But when peak, energy and capacity are known, the load factor is really not needed for power cost analysis. Therefore the load factor should not be used as indiscriminately as it has been in connection with generation and transmission cost.

The load factor of a consumer's load has a practical meaning only when other factors are known. A consumer with a high load factor is not necessarily a better consumer than one with a lower load factor. The consumer with the lower load factor may have his peak at night and it may cost less to serve him than it costs to serve the one with a higher load factor. Here, too, the load factor has no relationship to the installed capacity on the consumer's premises nor to the capacity of the utility equipment required to serve the consumer. The load factor is an utterly inadequate characterization of the consumer's load. Here, too, the peak and its qualifications as well as the energy used must be known, and when these are known the load factor is really not needed for analysis.

The peak establishes capacity cost, the energy quantity establishes other costs, the load factor alone establishes nothing. But it is useful and convenient to one who is familiar with the details of load conditions of a particular system, a particular power house or a particular load. When a utility man speaks of the load factor, it is to him a shorthand characterization of a condition, the details of which are known to him.

The case which is required in the use of the load factor in rates becomes obvious when the extreme case of a dump consumer is mentioned. Such a consumer may take energy from a system only for a short period of time. In spite of an extremely low load factor, a low rate is justified.

It is evident that a great amount of discretion is advisable when using the load factor for comparing two conditions with one another.

2. THE LOAD FACTOR. The load factor is probably the most used and most abused of all factors. It is the ratio of the average load over a designated period to the peak load occurring in that period and relates either to a consumer's load, the load of a power house or the load on a power system. It may be averaged over a month or over a year. It may be based on instantaneous peaks, 15-minute peak or hourly peak. It is generally based on the [illegible] but sometimes on both. Thus when the term load factor is used a number of qualifying statements are necessary. Furthermore, the load factor has no relationship to capacity and consequently no relationship to cost. A power house of 100,000 kw capacity may have a peak load of 50,000 kw and a load factor of 80 percent or it may have a peak of [illegible] kw and also a load factor of 80 percent. The load factor can be determined from a load curve without ever knowing the scale to which the curve is plotted. Thus the frequently made statement that when a power house operates at a certain load factor the cost is [illegible] per kwh is meaningless. As far as cost analysis of a power house or a power system is concerned, the load factor only becomes a meaningful [illegible] when either the energy or the peak with its qualifications as well as the capacity are also known. But when peak, energy and capacity are known, the load factor is really not needed for power cost analysis. Therefore the load factor should not be used so indiscriminately as it has been in connection with generation and transmission costs.

The load factor of a consumer's load has a practical meaning only when other factors are known. A consumer with a high load factor is not necessarily a better customer than one with a lower load factor. The consumer with the lower load factor may give the same rate return as it may that from the same [illegible] as the one with a higher load factor. Taken alone, the load factor has no relationship to the installed capacity of the consumer's premises and to the capacity of the utility equipment required to serve the consumer. The load factor is an overall incomplete characterization of the consumer's load. Here, too, the peak and its qualifications as well as the energy must be known, and when these are known the load factor is really not needed for analysis.

The peak establishes capacity cost, the energy generally establishes energy costs, the load factor alone establishes nothing. But it is useful and convenient to use when in dealing with the details of load conditions of a particular system, a particular power house or a particular load. When a utility man speaks of the load factor, it is to him a condensed characterization of a condition, the details of which are known to him.

The case which is repeated in the use of the load factor in rates becomes obvious when the extreme case of a dump consumer is mentioned. Such a consumer may take energy from a system only for a short period of time. In spite of an extremely low load factor, a low rate is justified.

It is evident that a great amount of discretion is advisable when using the load factor for comparing the conditions with one another.

3. THE RESPONSIBILITY LOAD FACTOR. This factor is not used as a characteristic of power houses or power systems. It is only used as a characteristic of a load, and as such it is of greater significance than the load factor, because it relates the load to the system at the time of the system peak. It is the ratio of the average load of a consumer to the peak responsibility of that consumer, expressed in percent. The consumer's peak responsibility is his load at the time of the system peak. Whereas the load factor cannot be greater than unity, the responsibility load factor can exceed unity. Whereas a consumer with a high load factor is not necessarily a better consumer than one with a lower factor, a consumer with a higher responsibility load factor may always be assumed to be a better consumer than one with a lower responsibility load factor. Be the allocation theory what it may, the peak responsibility of a consumer establishes to a considerable extent, if not altogether, his responsibility for fixed charges. Of course, here too, the factor alone is inadequate for any analysis. If the shape of a consumer's load curve, his maximum demand and his peak responsibility are all known, an analysis can be undertaken without the responsibility load factor. The responsibility load factor is also a shorthand expression for a known load condition, except that loads can be compared to some extent on the basis of this factor.

4. THE CAPACITY FACTOR AND THE PLANT FACTOR. According to the proposed ASA definitions, these two factors have the same meaning, except that the capacity factor relates to an individual machine and the plant factor to a whole power house or a power system.

Therefore, the plant factor alone will be considered here. It is the ratio of the average load to the aggregate rating of generating equipment, for a given period. Thus the annual plant factor in percent for a power house or a system is:

$$\frac{100 \times kwh}{8760 \times kw} = \frac{0.0114 \times kwh}{kw}$$

When related to a system the definition could be extended to include not only generating capacity, but also purchase capacity. In judging the reliability or utilization of facilities of a system, the purchase capacity may be considered additional available generating equipment.

Thus the plant factor relates output to capacity and is a picture of utilization of facilities and of investment. When the annual plant factor of a power house was 25 percent, it means that on the average throughout the year 25 percent of the generating capacity operated at full load and 75 percent was idle, or that 75 percent of the investment was dead. Whereas the load factor has no relationship to fixed charges, the plant factor establishes the fixed charges per kwh. A higher plant factor means a better utilization of generating facilities and lower fixed charges per kwh. Load conditions may make a high plant factor impossible or impractical, but the fact remains that the plant factor establishes the fixed charges per kwh definitely. Thus the plant factor may be considered by far the most important of all factors in power cost analysis.

The plant factor or a similar factor could be used for analyzing and comparing the utilization of transmission and distribution facilities, as for instance the annual over-all plant factor of all distribution transformers or of transmission lines. But this has not yet become common practice.

5. THE UTILIZATION FACTOR. Next in importance to the plant factor, the utilization factor presents a picture of the utilization of facilities at peak times and the amount of available reserve and excess capacity. It is the ratio of the maximum demand of a power house or a system to the rated capacity of the power house or system. The peak, of course, must be qualified in each case as to duration. Here, too, the purchase capacity can be included under "capacity," in addition to the generating capacity.

6. THE DEMAND FACTOR. The demand factor is the ratio of the maximum demand of a system to the total connected load of the system. It presents a picture of utilization of connected load. It is a shorthand expression of the degree of use of consumer's connected load at the time of the system peak. This factor is used principally in system design.

7. THE DIVERSITY FACTOR. The diversity factor is the ratio of the sum of all non-coincident maximum demands of the various loads to the system peak. It is never less than unity. A higher diversity factor indicates that the peaks of the various loads are better distributed over the system load curve, which is a favorable condition for the system. A high diversity factor calls for less system capacity for the same consumer peaks than a lower diversity factor. In a number of theories of allocation of fixed charges, that use the non-coincident demands instead of the peak responsibility as a basis, the diversity factor is introduced for the purpose of establishing a theoretical peak responsibility even for consumers whose load curves have no peak responsibility at all.

This is a very useful factor indeed, but it must be remembered that similar to the load factor, it has no relation to capacity and hence no direct relation to fixed charges. The diversity factor can also be established from load curves without knowing the scale to which they are drawn. It is only necessary to know the ratios of the scales of the various load curves to one another.

8. THE COINCIDENCE FACTOR. The coincidence factor is the reciprocal of the diversity factor, and hence is never greater than unity. In mathematical treatment the reciprocal frequently simplifies the treatment. In fact, the coincidence factor seems to be used more in mathematical treatment than the diversity factor.

9. THE OPERATION FACTOR. The operation factor is the ratio of the duration of actual service of a machine, a power house or a system to the total duration of the period considered. This presents a picture of what percentage of the time a machine or a power house was in service, regardless of the load which it carried. This factor is very seldom used. To many engineers a direct statement of the actual number of hours that a machine or a power house operated in a year, presents a better picture than the factor. But the factor is handy in mathematical treatment of allocation.